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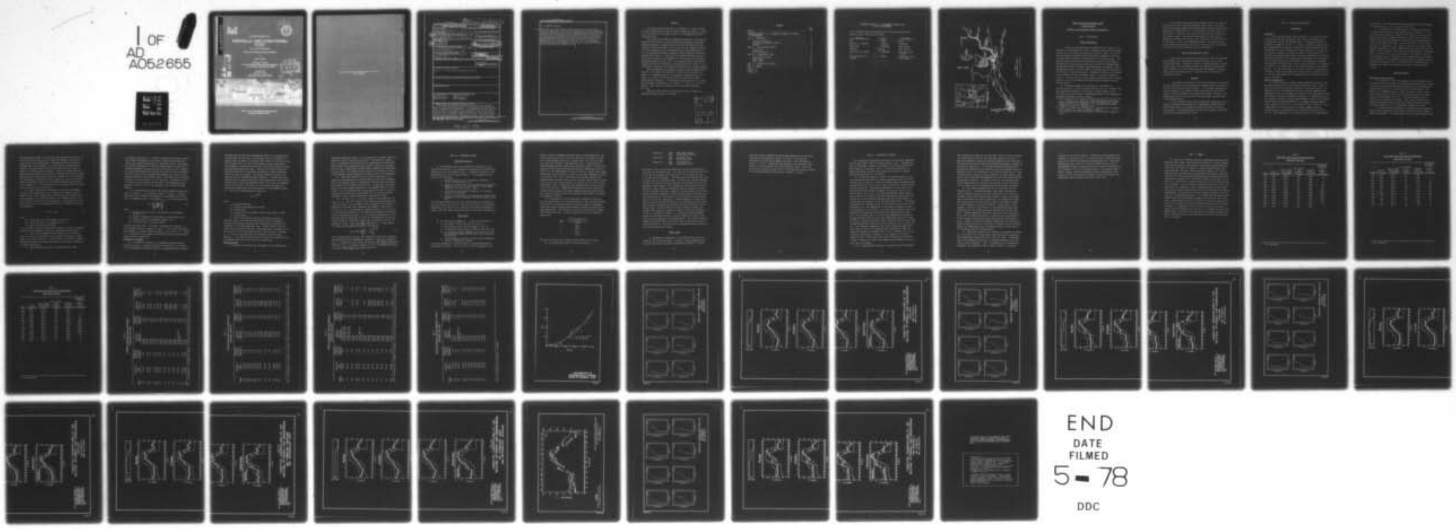

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TECHNICAL REPORT H-77-5

MARYSVILLE LAKE HYDROTHERMAL STUDY

Report 2, 2250-MW PROJECT

Hydraulic and Mathematical Model Investigation

by

Mark S. Dortch

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February 1978
Report 2 of a Series

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This study was conducted to determine the effect that the proposed Marysville Lake pump-storage hydropower (2250-mw power plant) project would have on downstream water temperatures. A one-dimensional numerical model was used for simulation and prediction of temperatures within and downstream of Marysville Lake. Two physical hydraulic models were used for study and description of the hydrodynamic response of the project. Information from the physical models was necessary to determine coefficients used by algorithms within the mathematical model. The mathematical model allowed (Continued)

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20. ABSTRACT (Continued).

simulation of the heat exchange characteristics so the thermal regimes within and downstream of the lake could be determined for various hydrologic and meteorologic conditions and various pumped-storage hydropower operations. Results of the study indicate that the temperatures should be within the objective band desired downstream during years with average or wetter than average hydrologic conditions. The study indicated that with the ultimate 2250-mw power plant fall temperature objectives would be exceeded by a maximum of 3°C for a 45-day period during much drier than average years. With the initial installed capacity of 1350 mw, fall temperature objectives could be met under all conditions studied.

PREFACE

The study reported herein was a continuation of a project study that was authorized by the Office, Chief of Engineers (OCE), U. S. Army, on 16 July 1975, at the request of the U. S. Army Engineer District, Sacramento (SPK).

This study was conducted to determine the ability of the proposed Marysville Lake Project to satisfy downstream temperature objectives. Peaking hydropower and pumped storage is planned for Marysville Lake. The power producing capacity of the project for this study was 2250 mw. A previous temperature study of Marysville Lake was conducted by the U. S. Army Engineer Waterways Experiment Station (WES) and reported in WES TR-H-77-5, Report 1. That study was concerned with the ability of the Marysville Lake Project designed for a 900-mw capacity to satisfy downstream temperature objectives. The large increase in flow regimes brought about by the formulation of the 2250-mw project required a reassessment of Marysville Lake thermal characteristics as reported herein.

This investigation was conducted during the period January 1977 to May 1977 in the Hydraulics Laboratory of WES under the direction of Messrs. H. B. Simmons, Chief of the Hydraulics Laboratory, and J. L. Grace, Jr., Chief of the Structures Division and Reservoir Water Quality Branch (Physical). The study was conducted by Mr. M. S. Dortch with assistance from Messrs. D. G. Fontane, C. H. Tate, Jr., and D. H. Merritt. This report was prepared by Mr. Dortch and reviewed by Mr. Grace.

Director of WES during this study was COL John L. Cannon, CE. Technical Director was Mr. F. R. Brown.

CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI) UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

Multiply	By	To Obtain
feet	0.3048	metres
miles (U. S. statute)	1.609344	kilometres
square feet	0.09290304	square metres
acre-feet	1233.482	cubic metres
cubic feet per second	0.02831685	cubic metres per second
feet per second per second	0.3048	metres per second per second

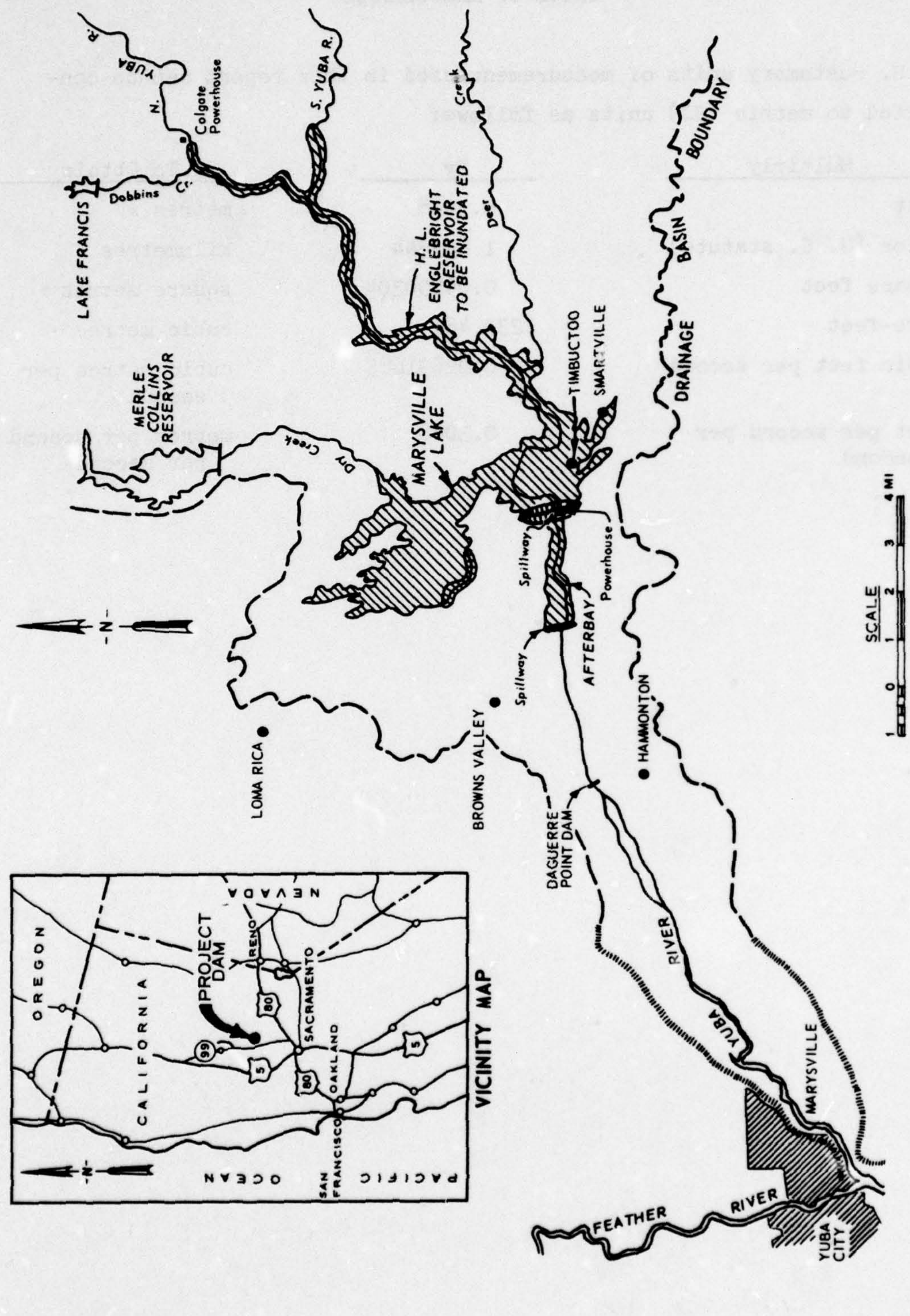


Figure 1. Location map

MARYSVILLE LAKE HYDROTHERMAL STUDY

2250-MW PROJECT

Hydraulic and Mathematical Model Investigation

PART I: INTRODUCTION

Project Description

1. During the planning stages of Marysville Lake (Figure 1), the project was reformulated such that the hydropower capacity was increased from 900 mw to an ultimate installation of 2250 mw. Most of the project features remained unchanged from the description presented in the previous WES report (Report 1)* that pertained to the 900-mw project. The Marysville Lake pool elevations and storage capacity did not change. The increase in power capacity required an increase in discharge rates between the forebay and afterbay during generation and pumpback. Maximum generation flows of 50,000 cfs** for the 900-mw project increased to 105,000 cfs for the 2250-mw project. Pumpback flow rates also increased from a maximum of 9,000 cfs (900-mw project) to 50,000 cfs (2250-mw project). Durations of flow did not change significantly; thus a greater volume of water was exchanged during generation and pumpback with the 2250-mw project.

2. The gross storage of the afterbay was increased from 40,400 acre-feet at el 233† to 80,400 acre-feet at el 270. However, for the study years presented in this report, a total storage of only 44,300 acre-feet was required. The minimum storage of the afterbay was increased from 8,900 to 9,300 acre-feet.

* D. G. Fontane et al., "Marysville Lake Hydrothermal Study; 900-mw Project; Hydraulic and Mathematical Model Investigation," Technical Report H-77-5, Report 1, May 1977, U. S. Army Engineer Waterways Experiment Station, CE, Vicksburg, Miss.

** A table of factors for converting U. S. customary units of measurement to metric (SI) units is presented on page 3.

† All elevations (el) cited herein are in feet referred to mean sea level.

3. The 2250-mw power plant would consist of four 450-mw pump turbines and one 450-mw conventional turbine. Each turbine would have a selective-withdrawal intake system consisting of vertically spaced ports opening into a common wet well. Flow would pass through a single selected port (no blending) into the wet well and from the wet well into the penstock intake. Each selective-withdrawal port would have an opening 25 ft high by 100 ft wide. Port elevations are discussed later in this report. Based on recommendations made in the previous study, it was decided that pumpback flow would be allowed to pass only through the port that was just previously used for withdrawal.

Need for and Purpose of Study

4. This study was conducted to determine the effect on downstream water temperatures of operating the Marysville Lake Project with a 2250-mw power plant. Temperature regimes of peaking hydropower, pumped-storage projects can be highly dependent upon pumpback and generation flows. Because of the much larger generation and pumpback flows associated with the 2250-mw project, it was necessary to completely reevaluate the project.

Approach

5. The thermal characteristics within and downstream of Marysville Lake were evaluated with the mathematical simulation model that was used for the 900-mw study described in Report 1. With greater magnitudes of flow and changes in the operation scheme associated with the 2250-mw project, it was anticipated that revisions would have to be made to the mathematical model to better describe the hydrothermal characteristics of the 2250-mw project.

6. As in the 900-mw study, physical hydraulic models were used to obtain an improved understanding of the hydrodynamic characteristics. Modifications made to the mathematical model were based on physical model results. Two physical models were used in the study, one of which was also used during the 900-mw study.

PART II: PHYSICAL MODEL STUDIES

Description

Lake model

7. The distorted scale (1:1600 horizontal, 1:160 vertical) model of Marysville Lake and afterbay that was used for the 900-mw project study was also used for the 2250-mw study. A complete description of the model is presented in Report 1. Because the geometry, surface area, and storage-elevation relation of Marysville Lake and afterbay did not change from that of the 900-mw project, major revision of the model was not required. However, an afterbay storage of 44,300 acre-feet was needed for the selected study years. This was approximately the maximum storage as reproduced in the existing model afterbay, so it was necessary to add some additional wall height to the afterbay for freeboard. Additionally, the intake-outlet port in the model dam had to be enlarged to account for the larger ports in the intake structure of the 2250-mw project. The only other change to the model consisted of replacing the reversible, variable-speed pump with a similar pump of greater capacity so that the larger generation and pumpback flows of the 2250-mw project could be simulated.

Model of pumpback jet

8. With the greater volumes of water pumped back each day, pumpback mixing associated with the 2250-mw project would have a greater effect on thermal stratification than that of the 900-mw project. The algorithms used by the mathematical model to describe pumpback mixing appropriately have a more significant influence for large pumpback flows. Particularly, the gross entrainment coefficient, E (reference Report 1), has a greater influence on mixing within Marysville Lake for the 2250-mw project than for the 900-mw project. For example, when the pumpback flow is 9,000 cfs and $E = 0.7$, the entrained flow is 6,300 cfs. For a larger pumped flow such as 33,000 cfs (typical summer condition, 2250-mw project), an entrained flow of 23,100 cfs would result with $E = 0.7$. The significance of the value of a given E is much greater

in the latter case, especially when considering that the total pumping time and the lake size are the same in both cases.

9. An undistorted 1:200-scale model of a single 100-ft-wide by 25-ft-high port was used to study pumped flow and evaluate E . The port was located within the end wall of an existing 3-ft-wide by 2-ft-deep by 25-ft-long rectangular transparent plastic flume. With the bottom of the flume corresponding to prototype el 200 (approximate reservoir bottom, Marysville Lake), the port was fixed at 1.50 ft above the bottom or prototype el 500. Water was pumped from a supply tank, through a rotameter and valve, through the wet well and port, into the flume. With the inside of the flume end wall representing the upstream face of the dam, the wet well was attached on the outside of the end wall covering the port. The model wet well reproduced the preliminary wet well design for the prototype, thus providing a reasonable velocity distribution through the port. The pumped flow was measured with the rotameter and scaled to prototype flow by means of Froude scaling criteria.

Tests and Results

Entrainment characteristics

10. Steady-state, short-term pumpback flow was studied with the undistorted model to determine the entrainment characteristics. Density stratification resulting from thermal stratification within Marysville Lake was simulated in the flume with saline and fresh waters. The density of the pumpback water was varied from test to test, but was always greater than the density of the surface water and less than the density of bottom water of the pool. A constant pumpback flow of 16,800 cfs was simulated in the model. This flow is typical of the pumped flow passing through a single port from a single pump turbine. An average summer pool of el 535 was used throughout the tests.

11. A density probe consisting of a conductivity and temperature sensor calibrated against known specific gravity was used to obtain density measurements. Flow measurements in the pool were obtained from

dye streak displacements. Dye particles were dropped into the pool. As the particles fell, vertical dye streaks were created. Fluid motion created a dye streak displacement. By recording the dye streak displacement with video equipment, velocities could be obtained during playback. By integrating the velocity distributions with respect to depth, unit discharges were calculated. Practically uniform flow was observed across the width of the flume at stations outside of the spreading and turbulent mixing zone of the jet; therefore the unit discharges were multiplied by the width to obtain volume flow rates. The velocity profiles were taken outside of the turbulent spreading and mixing zone of the pumpback jet. It was observed that the lateral spread of the jet was not restricted by the flume walls.

12. With a knowledge of the volume flow rates of the pumpback current and the pumping rate, it was possible to estimate the total amount of flow that was entrained by and mixed with the pumpback flow. The entrainment of flow causes the flow of the pumpback current to be greater than the flow rate of the pumpback jet. The pumpback jet actually induces flow. The volume rate of flow of the pumpback current can be described by

$$Q_c = Q_o + EQ_o \qquad (1)$$

where

Q_c = volume flow rate of the pumpback current, cfs

Q_o = volume flow rate of the pumpback jet, cfs

E = total entrainment coefficient

It is necessary to know the entrainment coefficient in order to properly account for the budgeting of water and temperature within the pool.

13. Most of the entrained flow was observed to come from the layers of the pool corresponding to the elevation of the port through which the jet entered the pool. This information is needed for mathematical model input and is mentioned again in the section on mathematical model modifications.

14. There was some difficulty in obtaining values of the

entrainment coefficient, E. Because the pumpback flow causes disturbances (water displacement) in the pool, internal gravity waves are created that complicate measurement of the advected flow. The internal waves caused displacements of the dye streaks, making it difficult to distinguish whether the motion was due to advection or waves. Numerous dye streak displacements were recorded during each test so that several velocity profiles could be obtained and averaged in an effort to damp periodic motion due to the internal waves. The average velocity profile was used to obtain a value for E for each test. An average value for E of about 1.0 was obtained from the tests. For mathematical model purposes, a value of $E = 1.0$ was applied to the flow from the pump turbine.

15. To substantiate the above test result, another procedure was used to estimate E. As presented in Report 1, there is a relation that fairly well describes the thickness of an interflow, such as that due to a pumpback current. The thickness, D, can be calculated from

$$D = 4.1\left(\frac{Q_c}{W\sqrt{\frac{\Delta\rho}{\rho_c}g}}\right)^{2/3} \tag{2}$$

where

W = average reservoir width at the elevation of the pumpback current, ft

$\Delta\rho$ = density difference of the epilimnion and hypolimnion, g/cc

ρ_c = average density of the pumpback current, g/cc

g = acceleration due to gravity, ft/sec^2

By dying the pumped flow, it was easy to determine the thickness, D, of the pumpback current. Knowing $\Delta\rho$ and W, Q_c could be calculated from Equation 2 and substituted into Equation 1 to solve for E. Values of E obtained this way compared favorably with those obtained from the average velocity computations.

Mixing due to pumpback

16. As discussed in Report 1, the pumpback current alters the density structure as it passes through the interflow zone. To account for the displacement and mixing caused by the pumpback current, a mixing

technique that was used in the mathematical model for the 900-mw study was also used for this study. The technique, which is discussed in greater detail in Report 1, is based on the concept of a portion of each of the layers within the zone of the pumpback current being removed, mixed together, returning the mixed water to the layers within the zone, and then mixing within each layer. The portion of water removed and mixed from each layer is computed by multiplying a mixing coefficient times the volume of the layer. The mixing technique is applied once during each day of mathematical model simulation. Physical model data indicated that the mixing coefficients decay exponentially with vertical distance above or below the pumpback current inflow layer. The pumpback current inflow layer is the layer of the pool where the lake water density most nearly equals the average density of the pumpback current, ρ_c . The form of this exponential equation is

$$\eta_i = Ae^{-BX_i} \tag{3}$$

where

η_i = mixing coefficient

e = natural logarithmic base (2.7183)

A,B = coefficients

X_i = distance from the pumpback current inflow layer to layer

i = layer number

17. Tests were conducted with the distorted-scale model of Marysville Lake to evaluate the coefficients A and B for Equation 3. Generation and pumpback operations were simulated for conditions corresponding to an average hydrologic year. Density profiles were obtained from the model periodically. Through analysis of changes in the density profiles over known time periods, it was possible to evaluate η_i . A fit of the data provided the coefficients A and B used in Equation 3. The values of A and B that were found to be appropriate for the 2250-mw project were 0.164 and 0.035, respectively.

Afterbay mixing

18. Although the afterbay can be assumed to be fully mixed for

mathematical modeling (Report 1), it is necessary to properly budget the advection of heat to and from the afterbay. As discussed in Report 1, this is accomplished by accounting for the pregeneration afterbay water (fully mixed) and the Marysville Lake generation water that is pumped back in a day. Pregeneration afterbay water and Marysville Lake generation water that is not pumped back is mixed in the afterbay to obtain a volume-weighted average temperature of afterbay water after generation.

19. Tests were conducted with the physical lake model to determine how much pregeneration afterbay water constituted the pumpback. With this knowledge, mixing of pregeneration afterbay water with generation water could be properly accounted for. Additionally, this information allows the average temperature of the pumpback water to be calculated. As in the 900-mw study, fluorescent dye was used to trace the pregeneration afterbay water being pumped back for various operation conditions. These testing procedures are explained in Report 1.

20. The ratio of V_p , the total volume of water pumped back in a day, to V_G , the total volume of water released during generation in a day, was found to be a predominant factor influencing the amount of pregeneration afterbay water comprising the pumpback. Additionally, the ratio of V_I , the pregeneration afterbay volume, to V_G was found to be an important parameter for determining the pumpback constituents. From the fluorescent dye tests, V_A , the volume of pregeneration afterbay water that is pumped back in a day, was determined for various operation conditions. Results of these tests are shown by a plot of the parameters V_A/V_p versus $\left(V_p/V_G\right)\left(V_I/V_G\right)$ (Plate 1). A least squares fit of these two parameters resulted in the equation

$$V_A = 1.486\, V_p\left(\frac{V_p}{V_G} \times \frac{V_I}{V_G}\right)^{1.916} \tag{4}$$

Test conditions shown in Plate 1 were typical of most of the conditions encountered during the mathematical simulations. Because the parameter V_A/V_p is undefined by test results for values of $\left(V_p/V_G\right)\left(V_I/V_G\right)$ greater than 0.50, V_A/V_p was assumed constant at 0.40 in the mathematical model for values of $\left(V_p/V_G\right)\left(V_I/V_G\right)$ greater than 0.50.

PART III: MATHEMATICAL MODEL

Model Modifications

21. Modifications made to the mathematical model used in the 900-mw study consisted of incorporating the physical model results that were discussed in the previous section. A complete description of the mathematical model can be found in Report 1. The modifications consisted of the following:

   a. Changed the value of the entrainment coefficient, E , from 0.7 (900-mw study) to 1.0.

   b. Changed the coefficients of the pumpback mixing equation (Equation 3) from A = 0.1675 and B = 0.118 (900-mw study) to A = 0.164 and B = 0.035.

   c. Incorporated a new equation (Equation 4) to describe mixing in the afterbay.

   d. Modified the description of entrained flow resulting from pumpback to allow entrainment from several layers of the pool.

The entrainment layers consist of all layers between the elevations of the invert and top of the port. Since the ports are 25 ft high and the mathematical layer size is 5 ft, there are five pumpback entrainment layers. The five layers contribute equally to the total entrained flow.

Model Input

22. The general data changes made for this study consisted of:

   a. The number of power units was set equal to 5.

   b. The individual port area was changed to 2500 ft^2.

   c. The minimum afterbay volume was fixed at 9300 acre-feet.

   d. An isothermal starting temperature of 12°C was used for the simulations rather than 8°C, which was used in the 900-mw study.

   e. The hydrology was revised to reflect partial impairment usage of upstream water rights.

A starting temperature of 12°C was found to be more appropriate for simulating this project. The use of an 8°C starting temperature was

based on observed temperature profiles taken at nearby Englebright and New Bullards Bar Reservoirs, which are practically isothermal at about 8°C at the beginning and end of a calendar year. Both of these lakes have high level releases. When Marysville Lake is simulated without pumped storage and with a high-level release (all year), a starting temperature of 8°C should be used because the lake temperatures return to about 8°C or 9°C isothermal at the end of the year. However, with pumped storage and low-level releases in the fall, the lake temperatures return to only about 12°C. This is reasonable since mixing resulting from pumped-storage causes more heat to enter the pool, and low-level releases in the fall do not allow the advection of heat out of the lake from the warmer upper layers. Simulations were conducted with a starting temperature of 8°C and 12°C. Temperatures predicted by the two simulations differed during the winter and early spring months; but after the model was allowed to simulate several spring months, almost identical temperature regimes were found.

23. The number of selective-withdrawal intakes for each power unit was reduced from 6 for the 900-mw study to 5 for the 2250-mw study. A conclusion of the previous study was that the number of withdrawal elevations could be reduced without adversely affecting the desired release temperatures. The elevations of several ports also were changed from the previous study. The port locations used for this study are shown below:

Port	Center-line Elevation ft msl
1	530.0
2	490.0
3	440.0
4	370.0
5	252.5

The port size used for this study was 100 ft wide and 25 ft high.

24. The study years used for this study consist of:

Study year 1	1962	Hydrology (average)
	1962	Meteorology (average)
Study year 2	1931	Hydrology (dry)
	1967	Meteorology (hot)
Study year 3	1942	Hydrology (wet)
	1963	Meteorology (cold)

Study years 1 and 3 are the same hydrologic and meteorologic years as those used for the 900-mw study. For study year 2, hydrologic year 1931 (a dry year with pumpback) was substituted for hydrologic year 1934 (a dry year without pumpback). The meteorologic year 1967 was also used for study year 2 in the 900-mw study. The hydrologic routings supplied by SPK for the 900-mw study were obtained for the condition of full impairments of water rights. Full impairments mean that the preimpoundment water rights upstream of Marysville Lake are assumed to be fully utilized throughout each year. However, the water rights are not fully utilized (partial impairments) during the winter months and portions of the spring and fall. This results in larger inflows and outflows than would occur with full impairments. Partial impairment of water utilization is a more realistic description of the hydrology and was used by SPK to develop the hydrologic routings and project operations for the 2250-mw study. Inflows to Marysville Lake, afterbay releases, pool storage, and irrigation diversions at Daguerre Point for study years 1, 2, and 3 are presented in Tables 1-3. The daily operation schedule planned for the 2250-mw project is quite different, in terms of flow rates, from that planned for the 900-mw project. The 2250-mw operation schedules provided by SPK for the three selected study years are presented in Tables 4-6. The flow rates and durations shown in Tables 4-6 are monthly average daily values.

Model Output

25. Mathematical simulations of the 2250-mw project were conducted for all three study years. Predicted in-lake temperature profiles for the three study years are presented in Plates 2, 4, and 6.

Predicted release, afterbay, and downstream temperatures for the three study years are presented in Plates 3, 5, and 7. The selective-withdrawal port selection throughout each year is also indicated in Plates 3, 5, and 7. Temperature objectives are to be satisfied "downstream" at the confluence of the Yuba and Feather Rivers. These objectives are the same as those used for the 900-mw study and are defined by the downstream objective band shown in Plates 3, 5, and 7.

PART IV: DISCUSSION OF RESULTS

26. Downstream temperatures stay within the objective temperature band for study years 1 and 3 as shown by Plates 3 and 7. Through careful port selection, it should be possible to stay within the band for years similar to study years 1 and 3. For prototype operations, it would be advisable to select ports based on the results of a mathematical operations model of the project.

27. It was not possible to operate the 2250-mw project as presently planned and stay within the desired temperature band at all times for study year 2 (Plate 5). Should the 2250-mw project be operated with pumpback during hot, dry (low pool) years, difficulty in staying within the band could occur. The release temperatures of study year 2 can be held within the band during the summer, but this will result in even warmer releases in the fall. The warmer-than-desired summer temperatures (Plate 5) are caused by the hotter-than-average meteorologic conditions that create additional warming within the stream between the afterbay and the confluence of the Yuba and Feather Rivers. The warmer-than-desired fall releases are due to the shortage of cold water in the Marysville pool. The combination of a dry year and pumpback reduced the availability of cold water. A dry year without pumpback could probably meet fall temperature objectives as was demonstrated by study year 2 of the 900-mw study. A hot year with pumpback and average hydrologic conditions can also meet fall temperature objectives as shown by Plate 8. The release plots in Plate 9 show that for a dry year with average meteorologic conditions, the fall objectives still could not be met. The downstream temperatures were cooler during the summer than those shown in Plate 5; the objective band could be met during the summer, but warmer fall releases would result. Therefore, the critical factor for study year 2 is that it is dry. Because it is dry the Marysville pool is lower than usual, thus containing less cold-water storage. Mixing that results from pumpback causes warming of the cold water that is available.

28. A simulation was conducted to determine how the downstream

water temperatures predicted for study year 2 with the project differed from those predicted for the same study year without the project. To make this comparison, predicted downstream temperatures for study year 2 were plotted with predicted natural downstream temperatures (without the project) for study year 2. The natural downstream temperatures were developed by routing inflows to Marysville from the headwater region of Marysville Lake to the confluence of the Yuba and Feather Rivers. Heat exchange for this stream routing was applied in the same manner as that used to obtain the downstream temperatures for the lake simulations and is explained in Report 1. As shown by Plate 10, the predicted downstream temperatures with and without the project are very similar except in the fall where the temperatures with the project are warmer.

29. The results discussed thus far are associated with the 2250-mw project. As presently planned, the project would have an initial installed capacity of 1350 mw, consisting of one 450-mw conventional turbine and two 450-mw pump turbines. Design of the power plant would provide for future installation of two additional 450-mw pump turbines when the future need for power is confirmed, bringing the total capacity of the plant to 2250 mw. Because there is less pumpback, it would be less difficult to meet downstream temperature objectives with the 1350-mw power plant than with the 2250-mw power plant. Because temperature objectives could be met for study years 1 and 3 with the 2250-mw power plant, it should be even less difficult to meet objectives during these study years with the 1350-mw power plant. However, because the downstream temperatures were outside the objective band during part of study year 2 (2250 mw), it was not known whether the temperatures could be maintained within the band during this study year with the 1350-mw project.

30. Simulations therefore were conducted to determine the effect that the project with a 1350-mw power plant would have on downstream water temperatures during study year 2 (dry, hot year). Coefficients used by the mathematical model for the 2250-mw simulations were also used for these simulations. This is considered to be a conservative assumption. The hydrologic input is shown in Table 2. Operation

schedules are presented in Table 7. Results of these simulations are presented in Plates 11 and 12. As shown by Plate 12, downstream temperatures are within the objective band during the fall. Downstream temperatures were as much as 2°C above the band from late July to mid-September because of warming that occurs between the afterbay and the confluence of the Yuba and Feather Rivers. By releasing colder water in summer, objective temperatures could be maintained in the summer, but this would deplete cold-water storage to the extent that warmer-than-desired releases would result in the fall.

PART V: SUMMARY

31. This study indicated that water temperatures downstream from Marysville Lake project could be maintained within the desired temperature range during years with average or wetter-than-average hydrologic conditions, with either a 1350-mw or a 2250-mw pumped-storage power plant operating. The model studies indicated, however, that with the 2250-mw project operating under the much-drier-than-average conditions experienced in 1931, the desired downstream water temperatures would be exceeded by a maximum of 3°C from mid-July through mid-September and by about 2°C in mid-October, gradually decreasing to desired levels by the end of November. With the initially installed 1350-mw power plant operating under 1931 conditions, desired temperatures would be met during the fall, but would be exceeded by as much as 2°C from late July through mid-September. By modifying the amount of pumpback during critical periods or by taking other measures, it is probable that the desired water temperatures could be maintained throughout the year under 1931 conditions. Other measures that could be taken, for instance, might involve release of cold water that would be available within the Dry Creek Arm (see Report 1, paragraph 33) down Dry Creek to mix with the water released from the afterbay on the Yuba River or to excavate the connecting channel deeper to allow the cold water below the connecting channel invert in the Dry Creek Arm to mix with water in the Yuba River Arm (main part of the lake).

Table 1

Hydrologic Input Data, Partial Impairments

Hydrologic Year 1962

Month	Inflow cfs per day	End of Month Lake Storage × 1000 AF*	End of Month Lake Elevation ft/msl	Afterbay Release cfs per day	Irrigation Withdrawal at Daguerre Point cfs per day
Jan	1563	676.9	521	1540	0
Feb	4331	690.7	523	4080	0
Mar	2717	773.1	537	1380	50
Apr	2501	772.0	537	2520	310
May	2244	769.1	537	2290	800
Jun	2364	765.6	536	2420	1000
Jul	2288	760.9	535	2360	1130
Aug	1774	756.8	535	1840	1030
Sep	1284	749.8	534	1400	800
Oct	5142	736.0	531	5370	360
Nov	1245	676.0	521	2250	0
Dec	2223	676.0	521	2220	0

* AF = acre-feet.

Table 2

Hydrologic Input Data, Partial Impairments

Hydrologic Year 1931

Month	Inflow cfs per day	End of Month Lake Storage × 1000 AF*	End of Month Lake Elevation ft/msl	Afterbay Release cfs per day	Irrigation Withdrawal at Daguerre Point cfs per day
Jan	1669	677.1	521	1660	0
Feb	1830	677.6	521	1820	0
Mar	2017	677.6	521	2020	50
Apr	1462	676.5	521	1480	310
May	1306	673.0	520	1360	800
Jun	1281	669.7	520	1330	840
Jul	1124	655.1	517	1350	930
Aug	1039	639.6	514	1280	860
Sep	817	622.9	511	1090	670
Oct	998	621.4	511	1020	340
Nov	857	621.4	511	860	0
Dec	1311	667.5	519	560	0

* AF = acre-feet.

Table 3

Hydrologic Input Data, Partial Impairments

Hydrologic Year 1942

Month	Inflow cfs per day	End of Month Lake Storage × 1000 AF*	End of Month Lake Elevation ft/msl	Afterbay Release cfs per day	Irrigation Withdrawal at Daguerre Point cfs per day
Jan	6801	686.5	523	6630	0
Feb	7714	706.6	526	7360	0
Mar	2909	795.3	541	1470	50
Apr	5324	894.4	557	3570	310
May	4956	916.0	560	4690	800
Jun	3788	916.0	560	3780	1000
Jul	3091	910.8	559	3170	1130
Aug	1717	906.2	559	1790	1030
Sep	1258	800.0	542	3040	800
Oct	1258	736.0	531	2290	360
Nov	973	676.0	521	1980	0
Dec	2334	676.0	521	2330	0

* AF = acre-feet.

Table 4

Operation Schedule, Partial Impairments

Hydrologic Year 1962

Month	Generation Rate cfs	Generation Duration hr per day Mon-Sat	Pumpback Rate, cfs Mon-Fri	Pumpback Duration hr per day Mon-Fri	Pumpback Rate, cfs Sat	Pumpback Duration hr per day Sat
Jan	95,900	1.99	33,800 16,900	0.09 8.91	16,900	6.94
Feb	95,900	2.25	16,900	6.95	16,900	1.15
Mar	92,700	2.00	31,000 15,500	0.84 8.16	15,500	7.65
Apr	91,300	2.07	14,800	8.67	14,800	4.58
May	91,000	2.01	14,700	8.64	14,700	4.94
Jun	92,100	2.69	30,600 15,300	3.42 5.58	15,300	8.62
Jul	95,000	4.25	49,500 33,000	3.05 5.95	33,000 16,500	8.60 0.40
Aug	95,300	4.25	50,100 33,400	3.59 5.41	33,400 50,100	8.02 0.98
Sep	94,700	3.77	49,200 32,800	1.70 7.30	16,400 32,800	0.29 8.71
Oct	93,600	2.57	15,900 Mon-Thurs 15,900 Fri	7.00 5.93	0	0
Nov	94,400	2.06	16,300	8.61	16,300	5.34
Dec	95,900	1.99	16,900	8.16	16,300	5.01

Note: No generation or pumpback on Sundays. There are two pumpback periods during a day for several months.

Table 5

Operation Schedule, Partial Impairments

Hydrologic Year 1931

Month	Generation Rate cfs	Generation Duration hr per day Mon-Sat	Pumpback Rate, cfs Mon-Fri	Pumpback Duration hr per day Mon-Fri	Pumpback Rate, cfs Sat	Pumpback Duration hr per day Sat
Jan	94,700	1.42	16,400	5.75	16,400	3.32
Feb	95,000	1.58	16,500	6.45	16,500	3.81
Mar	94,700	1.42	16,400	5.24	16,400	2.29
Apr	94,700	1.47	16,400	6.35	16,400	4.13
May	95,000	1.41	16,500	6.16	16,500	4.18
Jun	95,900	1.91	16,900	8.95	16,900	7.02
Jul	98,800	3.04	35,800 17,900	5.94 3.06	35,800 17,900	4.11 4.89
Aug	99,700	3.03	36,200 18,100	6.04 2.96	36,200 18,100	4.30 4.70
Sep	100,100	2.67	36,400 18,200	4.23 4.77	36,400 18,200	2.83 6.17
Oct	98,800	1.84	17,900	8.79	17,900	7.37
Nov	98,10C	1.47	17,700	6.97	17,700	5.81
Dec	96,600	1.42	17.100	7.22	17,100	6.44

Note: No generation or pumpback on Sundays. There are two pumpback periods during a day for several months.

Table 6

Operation Schedule, Partial Impairments

Hydrologic Year 1942

Month	Generation Rate cfs	Generation Duration hr per day Mon-Sat	Pumpback Rate, cfs Mon-Fri	Pumpback Duration hr per day Mon-Fri	Pumpback Rate, cfs Sat	Pumpback Duration hr per day Sat
Jan	95,600	2.00	16,800 Mon only 16,800 Tues only	1.94 0.22	0	0
Feb	95,300	2.23	16,700 Mon only 16,700 Tues only	2.17 0.43	0	0
Mar	91,900	2.00	15,100 30,200	8.14 0.86	15,100	7.53
Apr	87,800	2.11	12,600	7.87	12,600	1.06
May	85,400	2.05	10,500 Mon-Thurs 10,500 Fri	5.99 1.27	0	0
Jun	86,100	2.77	22,400 11,200	4.18 4.82	11,200	5.08
Jul	88,100	4.41	38,400 25,600	6.39 2.61	38,400 25,600	0.43 8.57
Aug	88,400	4.41	39,000 26,000	8.71 0.29	39,000 26,000	5.36 3.64
Sep	90,200	3.84	42,600 28,400	1.26 7.74	28,400 14,200	5.06 3.94
Oct	92,100	2.59	30,600 15,300	3.02 5.98	15,300	8.38
Nov	94,400	2.06	32,600 16,300	0.06 8.94	16,300	6.09
Dec	95,900	1.99	16,900	8.02	16,900	4.65

Note: No generation or pumpback on Sundays. There are two pumpback periods during a day for several months.

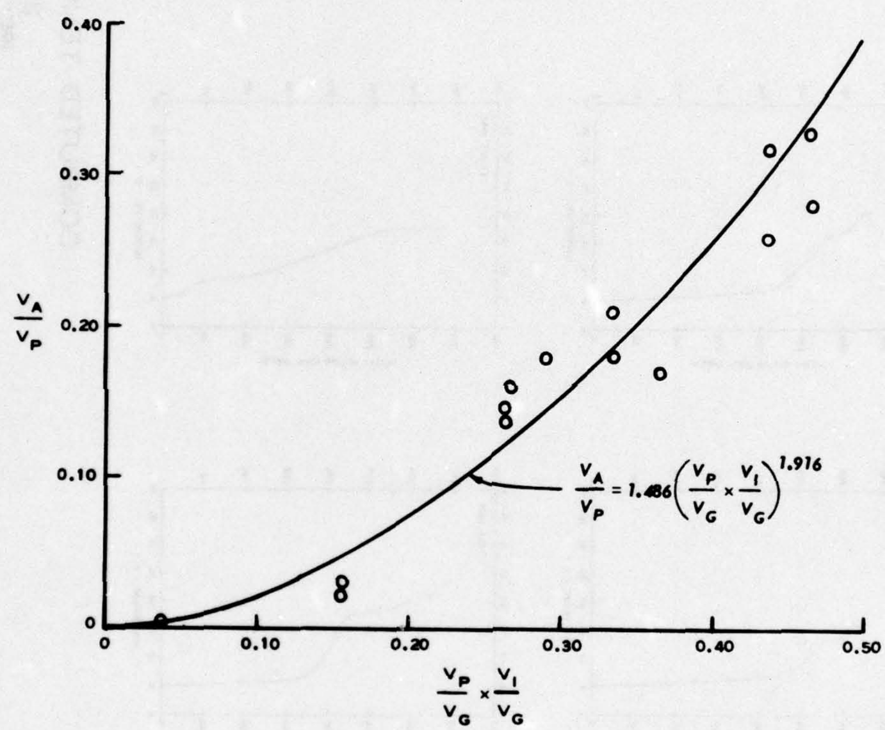
Table 7

Operation Schedule, Partial Impairment, 1350 mw

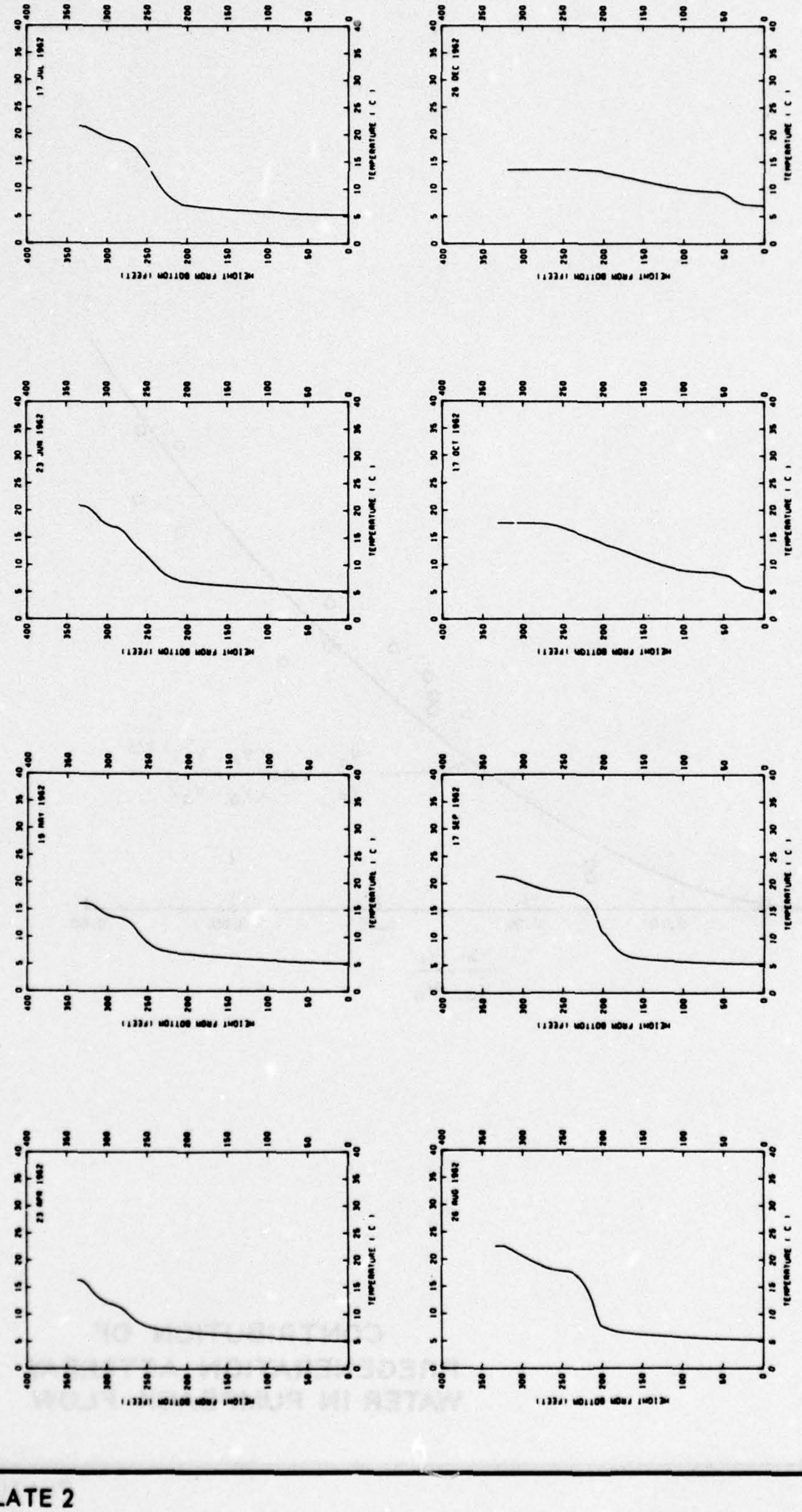
Hydrologic Year 1931

Month	Generation Rate cfs	Generation Duration hr per day Mon-Sat	Pumpback Rate, cfs Mon-Fri	Pumpback Duration hr per day Mon-Fri	Pumpback Rate, cfs Sat	Pumpback Duration hr per day Sat
Jan	56,300	1.45	16,000	2.65	16,000	0.15
Feb	56,300	1.63	16,000	3.03	16,000	0.30
Mar	56,300	1.45	16,000 Mon-Thurs 16,000 Fri	2.12 1.21	0	0
Apr	56,300	1.51	16,000	3.10	16,000	0.91
May	56,300	1.45	16,000	3.10	16,000	1.06
Jun	56,800	1.96	16,400	4.87	16,400	2.88
Jul	57,900	3.16	17,100	8.77	17,100	6.93
Aug	58,500	3.15	17,500	8.78	17,500	7.05
Sep	58,900	2.78	17,700	7.72	17,700	6.29
Oct	58,500	1.89	17,500	4.91	17,500	3.53
Nov	58,100	1.51	17,300	3.85	17,300	2.66
Dec	57,400	1.45	16,800	4.18	16,800	3.39

Note: No generation or pumpback on Sundays.

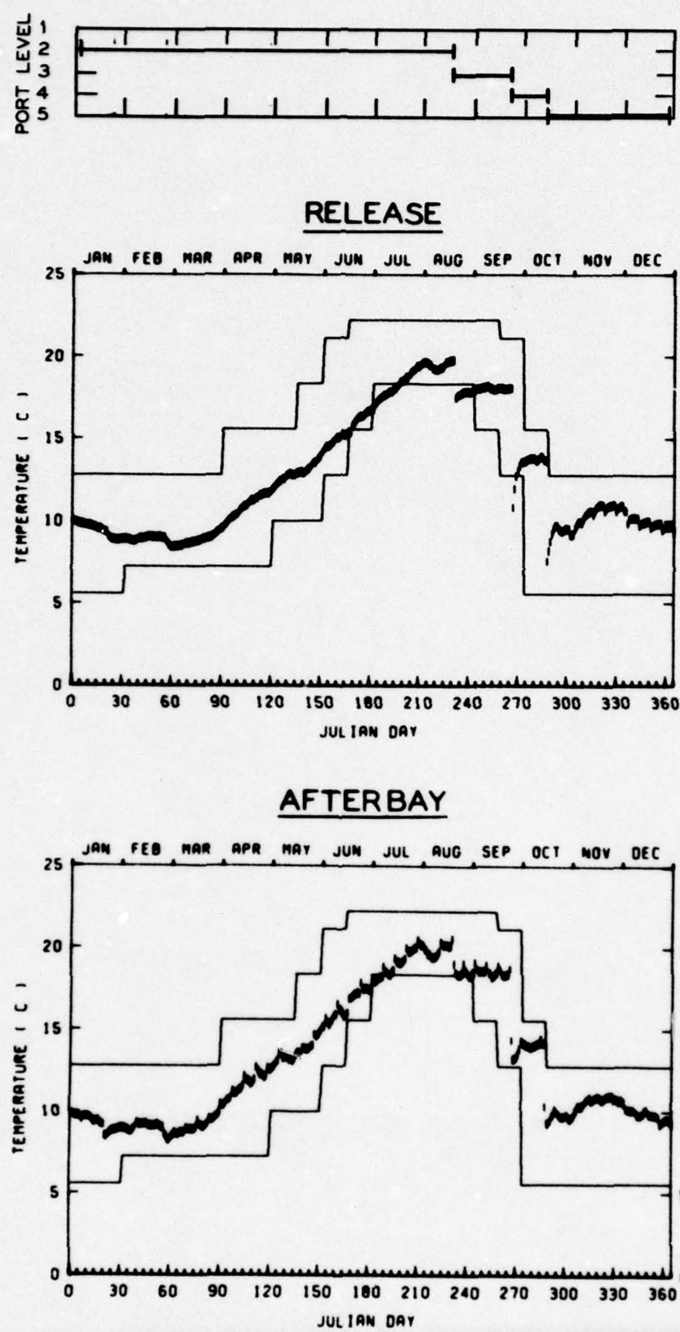


CONTRIBUTION OF PREGENERATION AFTERBAY WATER IN PUMPBACK FLOW

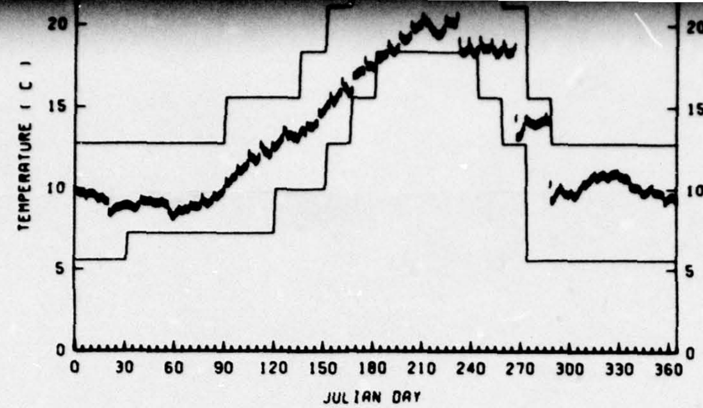


COMPUTED TEMPERATURE PROFILES
2250-MW
1962 HYDROLOGY
1962 METEOROLOGY

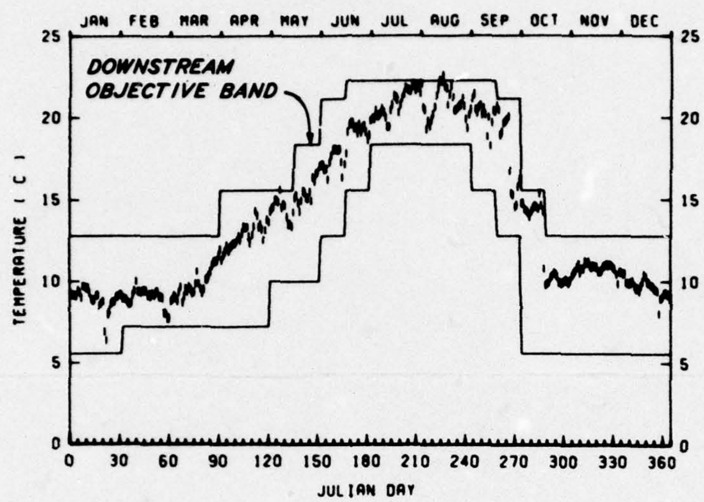
PLATE 2



PORT LEVEL
1
2
3
4
5
RELEASE
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
0 5 10 15 20 25
0 30 60 90 120 150 180 210 240 270 300 330 360
JULIAN DAY
AFTERBAY
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
0 5 10 15 20 25
0 30 60 90 120 150 180 210 240 270 300 330 360
JULIAN DAY



DOWNSTREAM



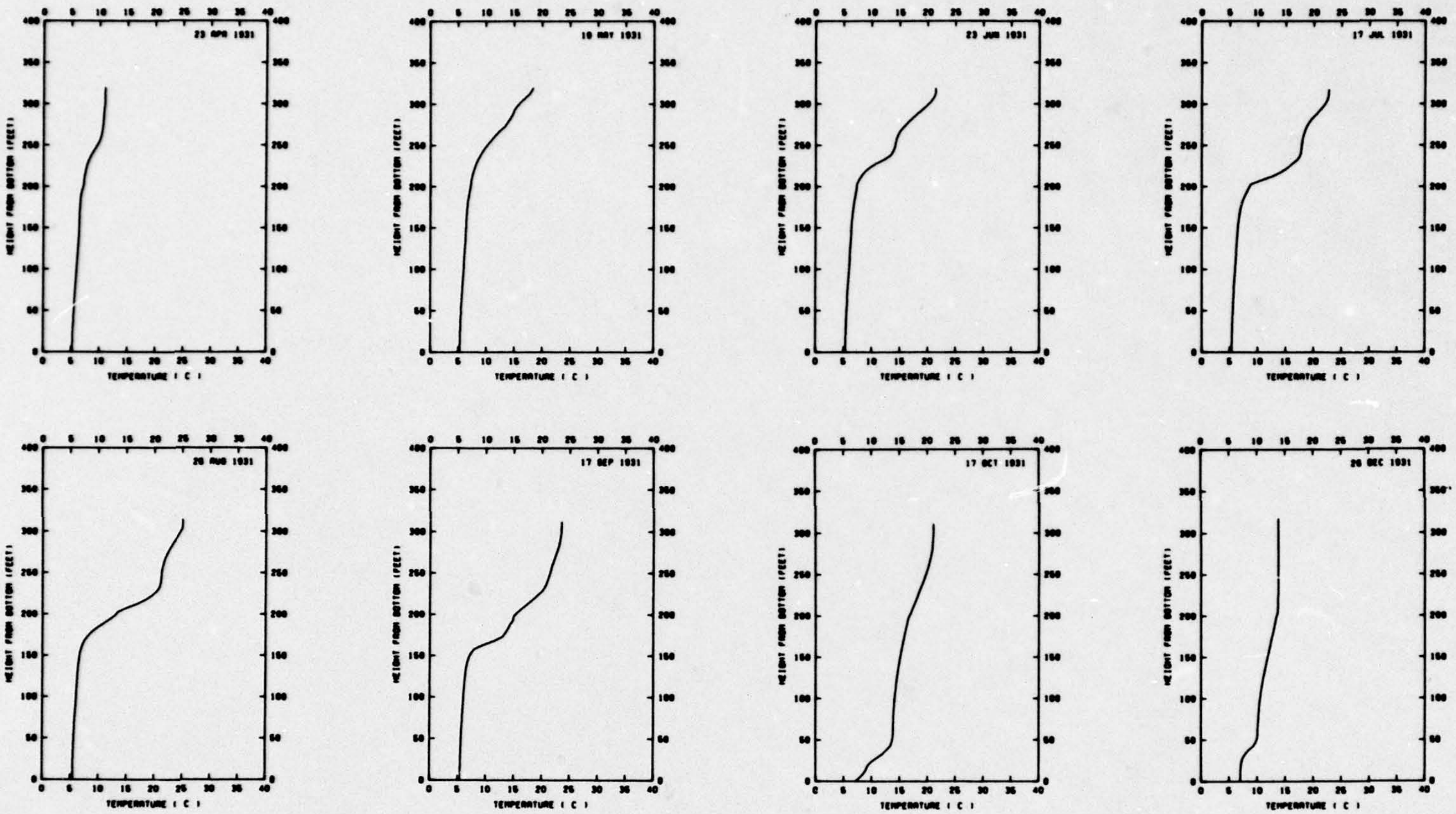
NOTE: THE OBJECTIVE BAND IS APPLICABLE ONLY FOR THE COMPUTED DOWNSTREAM TEMPERATURES. THE BAND ON THE RELEASE AND AFTERBAY TEMPERATURE PLOTS IS FOR REFERENCE ONLY.

COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM

2250-MW

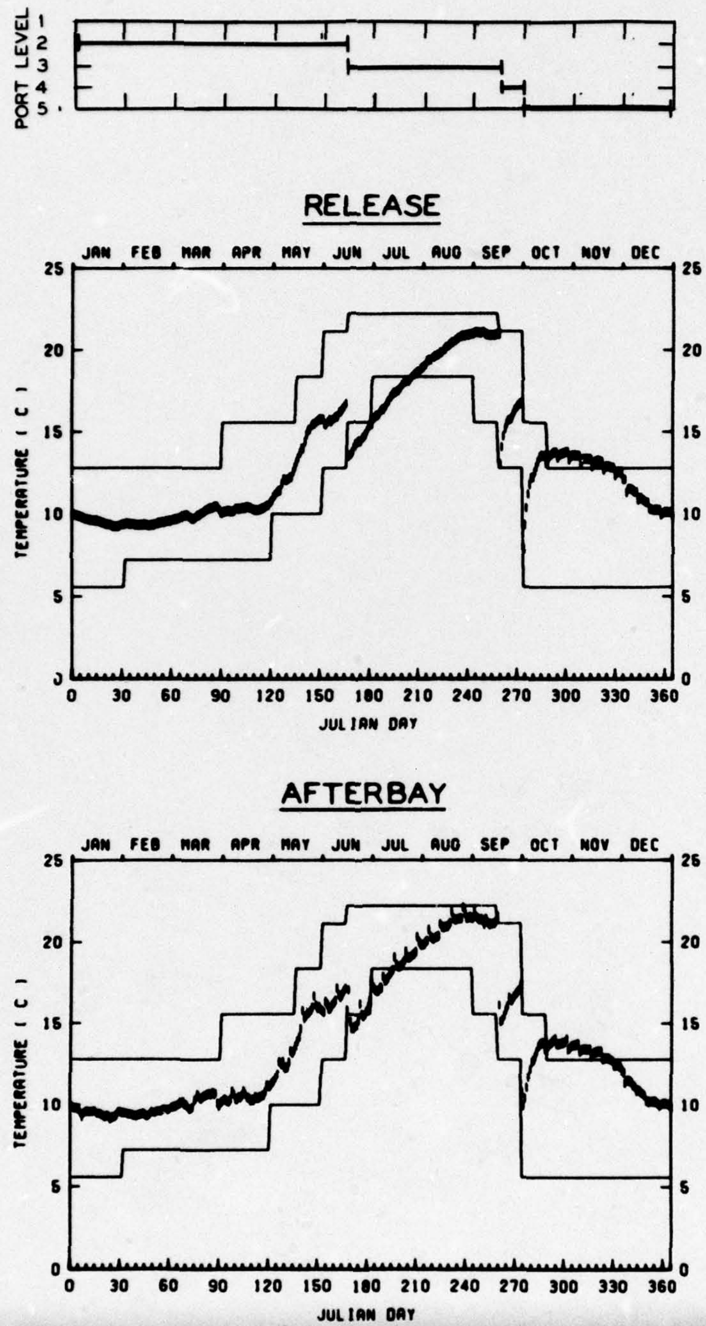
1962 HYDROLOGY

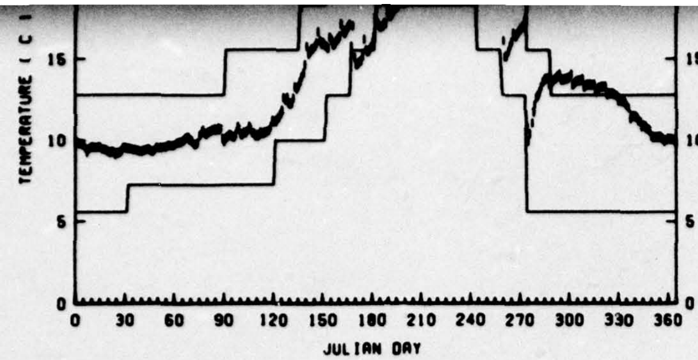
1962 METEOROLOGY



COMPUTED TEMPERATURE PROFILES
2250-MW
1931 HYDROLOGY
1967 METEOROLOGY

PLATE 4


PORT LEVEL
RELEASE
AFTERBAY
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
JULIAN DAY



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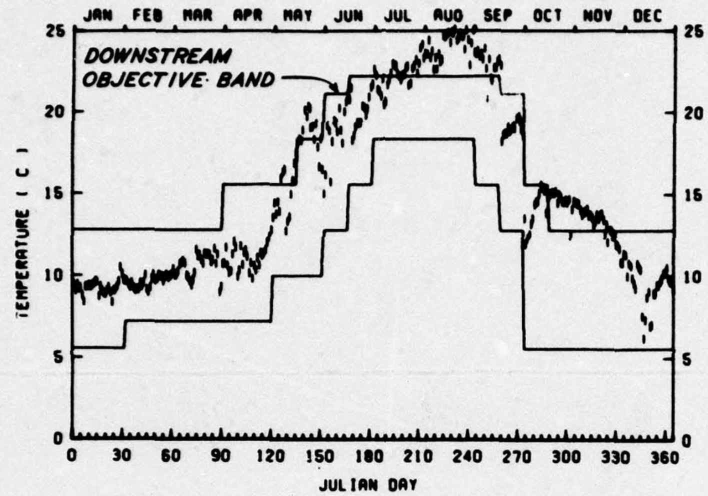

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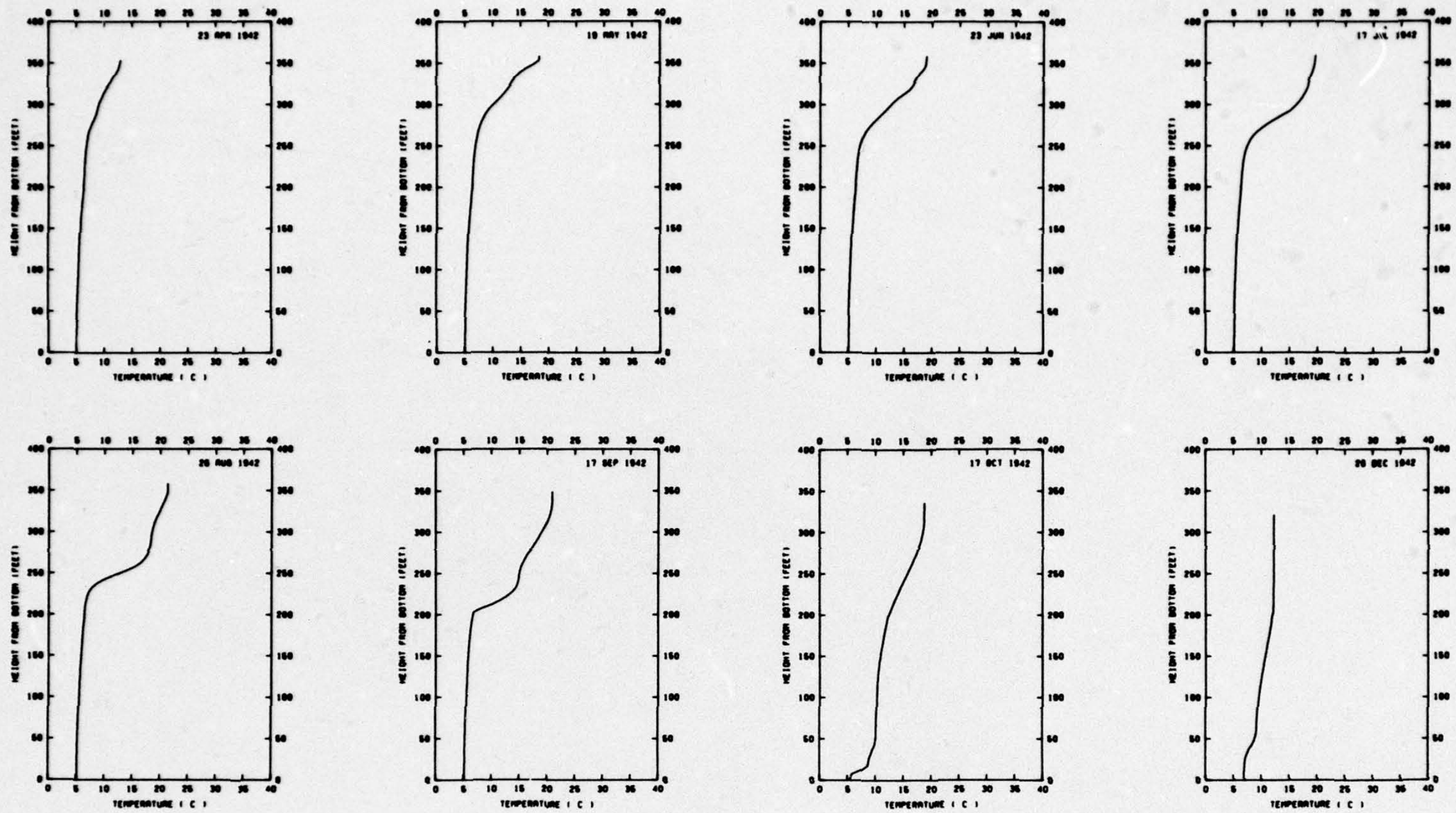
COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM

2250-MW

1931 HYDROLOGY

1967 METEOROLOGY

2



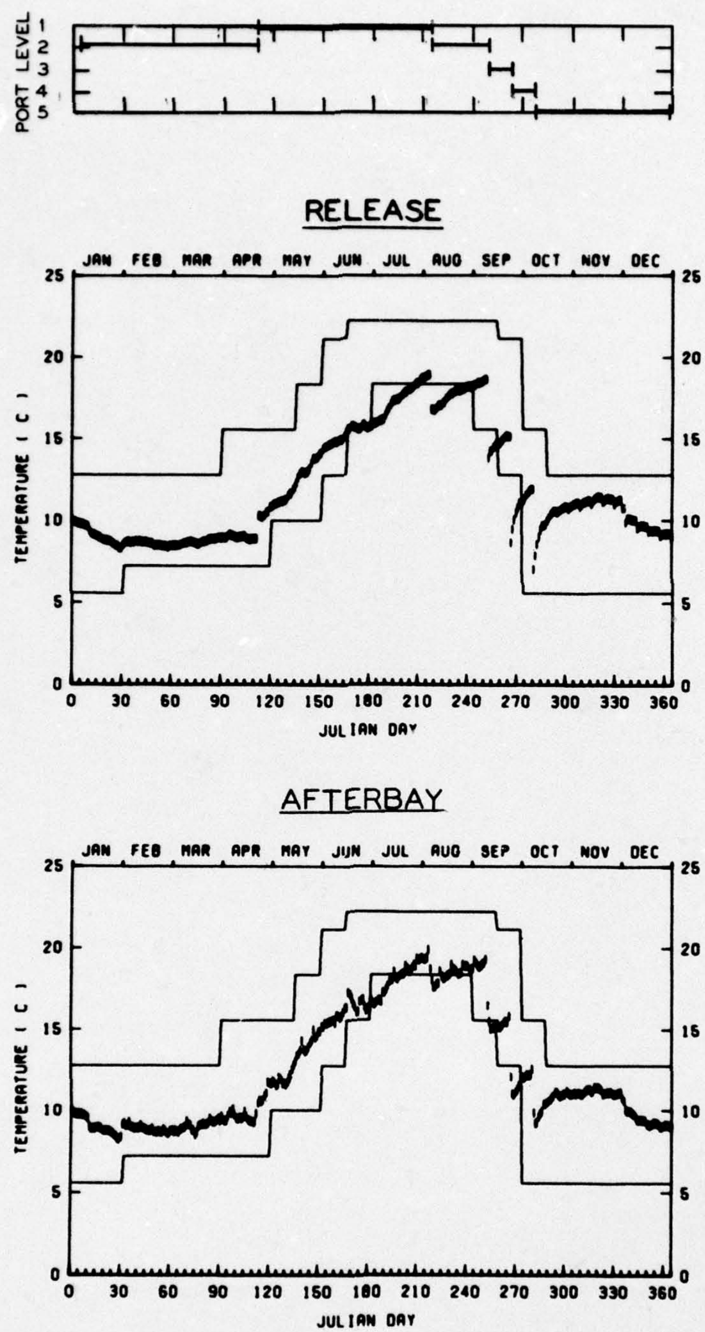
COMPUTED TEMPERATURE PROFILES

2250-MW

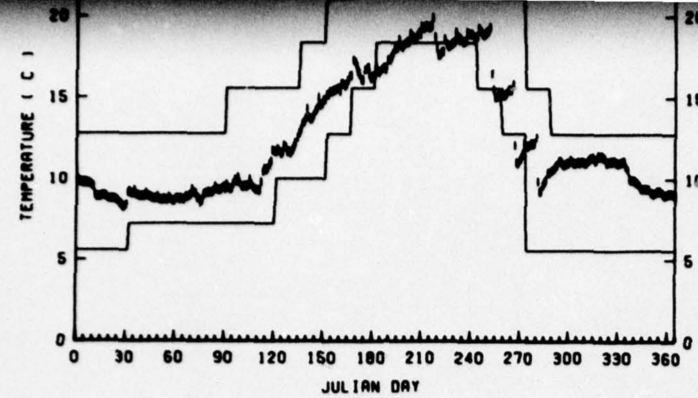
1942 HYDROLOGY

1963 METEOROLOGY

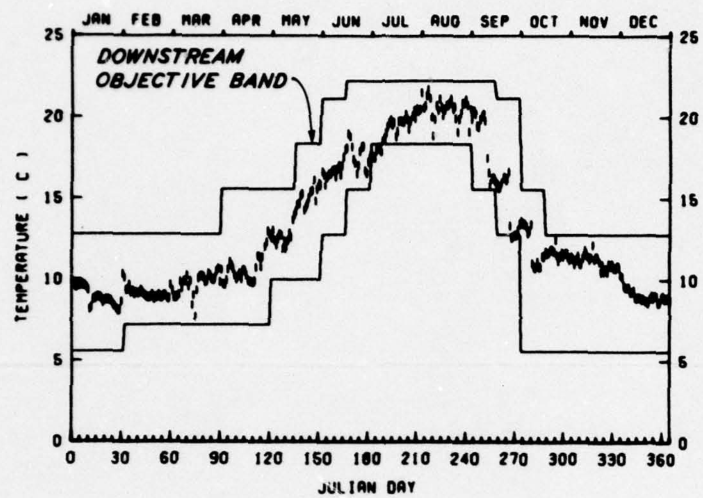
PLATE 6


PORT LEVEL
1
2
3
4
5
RELEASE
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
0 5 10 15 20 25
0 30 60 90 120 150 180 210 240 270 300 330 360
JULIAN DAY
AFTERBAY
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
0 5 10 15 20 25
0 30 60 90 120 150 180 210 240 270 300 330 360
JULIAN DAY

DOWNSTREAM



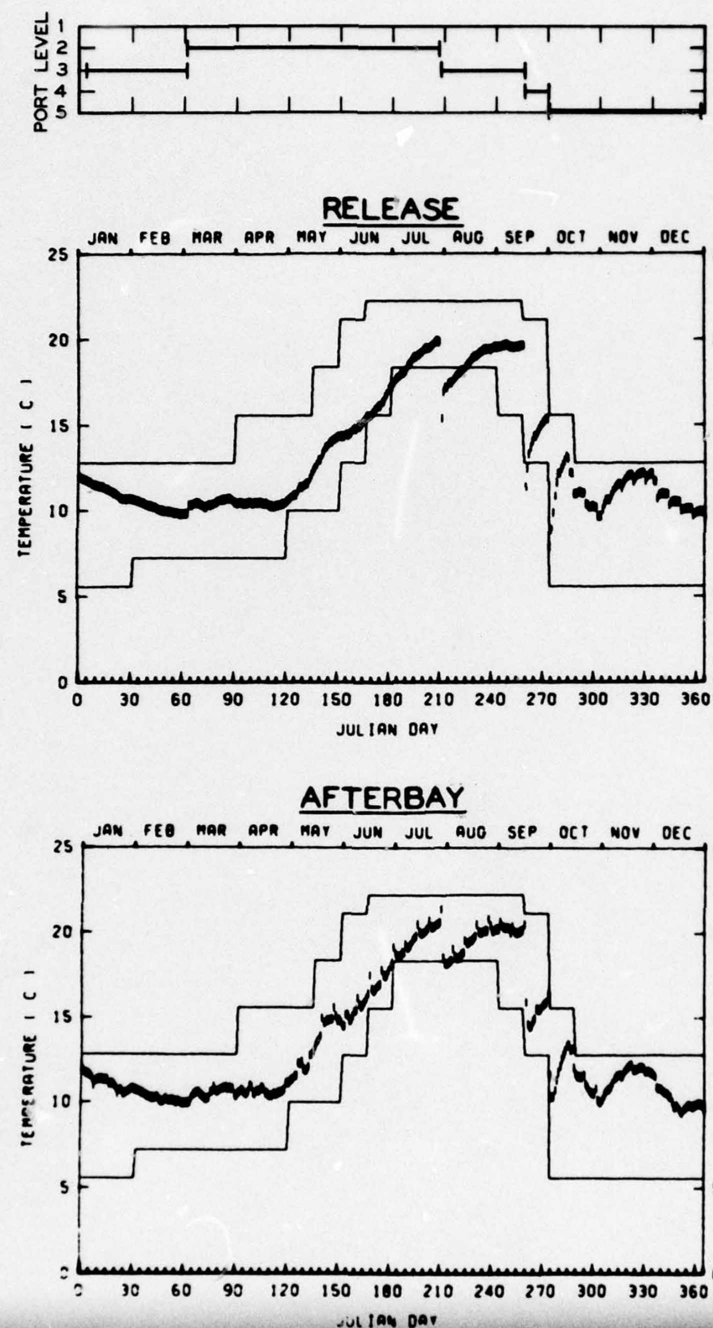
DOWNSTREAM



NOTE: THE OBJECTIVE BAND IS APPLICABLE ONLY FOR THE COMPUTED DOWNSTREAM TEMPERATURES. THE BAND ON THE RELEASE AND AFTERBAY TEMPERATURE PLOTS IS FOR REFERENCE ONLY.

COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM
2250-MW
1942 HYDROLOGY
1963 METEOROLOGY

2



PORT LEVEL
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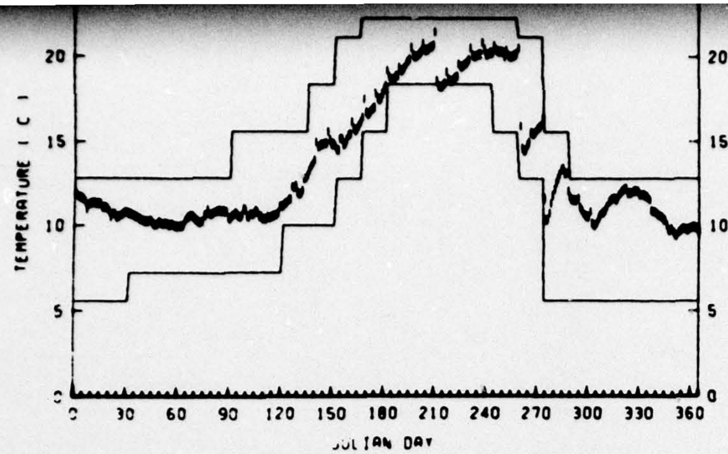
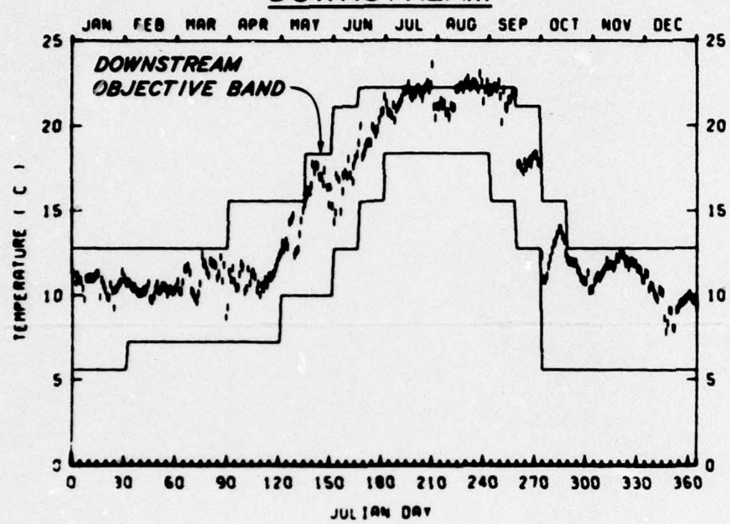
RELEASE
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
0 5 10 15 20 25
0 30 60 90 120 150 180 210 240 270 300 330 360
JULIAN DAY
AFTERBAY
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
0 5 10 15 20 25
0 30 60 90 120 150 180 210 240 270 300 330 360
JULIAN DAY



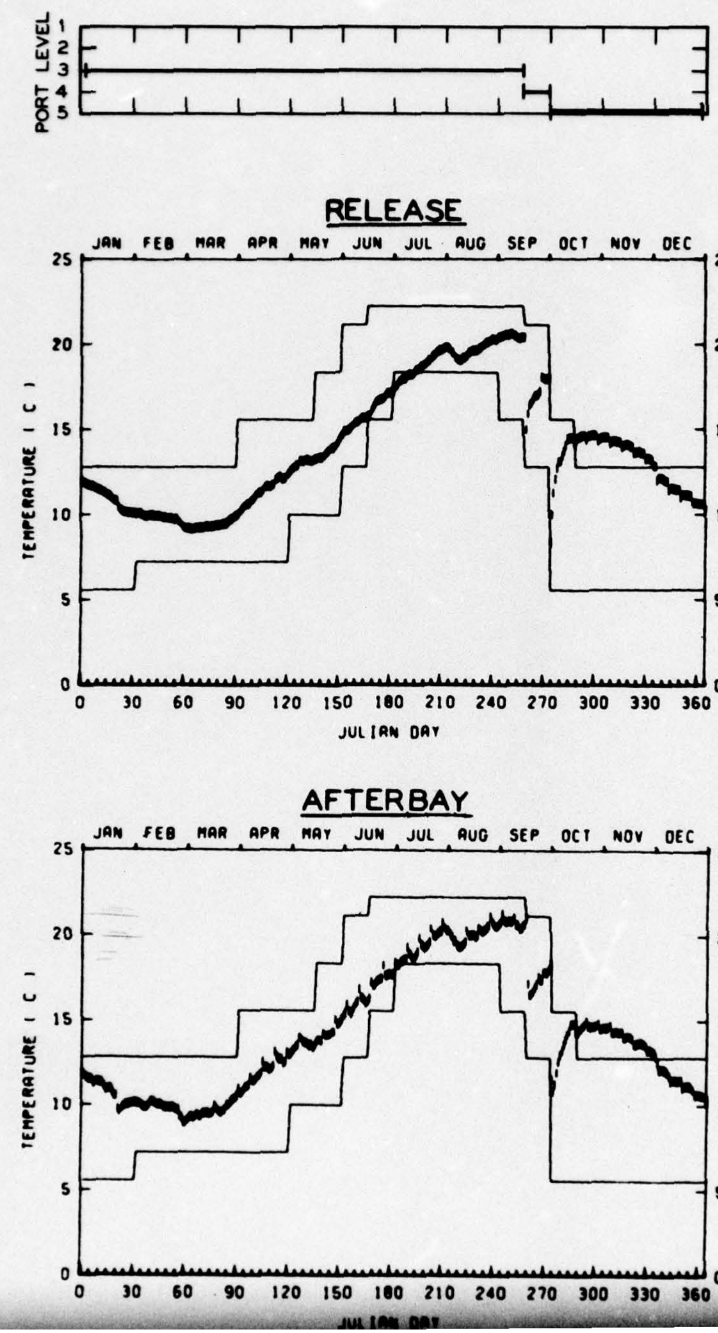
DOWNSTREAM



NOTE: THE OBJECTIVE BAND IS APPLICABLE ONLY FOR THE COMPUTED DOWNSTREAM TEMPERATURES. THE BAND ON THE RELEASE AND AFTERBAY TEMPERATURE PLOTS IS FOR REFERENCE ONLY.

2250-MW

COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM
1962 HYDROLOGY (AVERAGE)
1967 METEOROLOGY (HOT)


PORT LEVEL
1
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5
RELEASE
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
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15
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25
0 30 60 90 120 150 180 210 240 270 300 330 360
JULIAN DAY
AFTERBAY
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
0
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10
15
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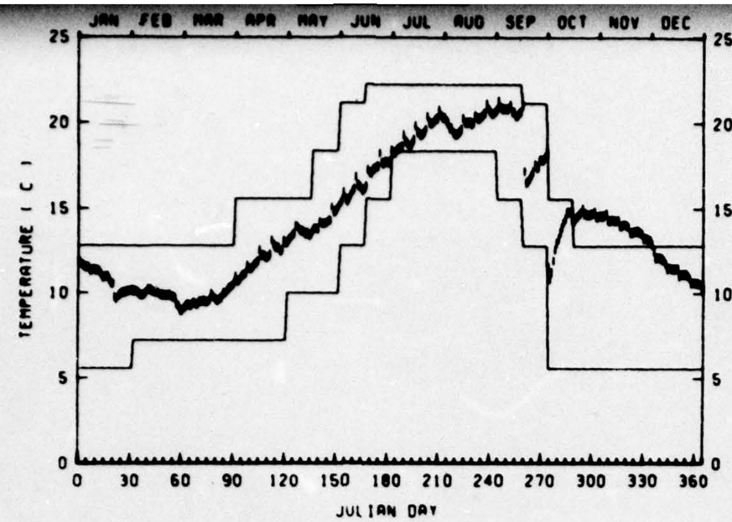
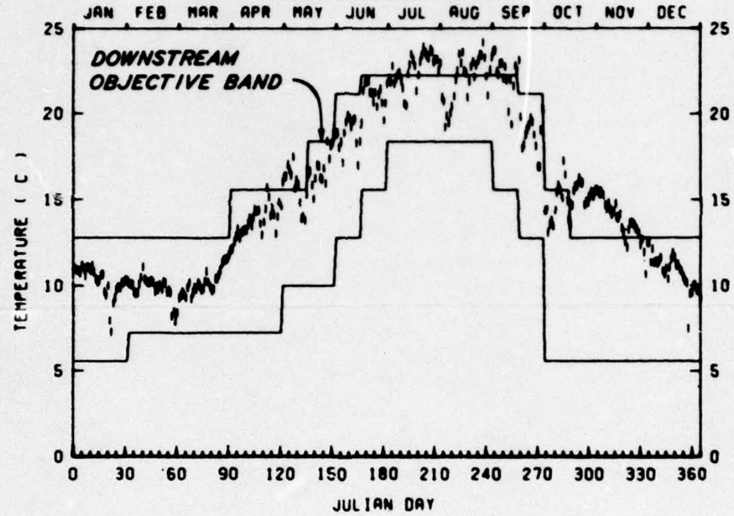
0 30 60 90 120 150 180 210 240 270 300 330 360



DOWNSTREAM



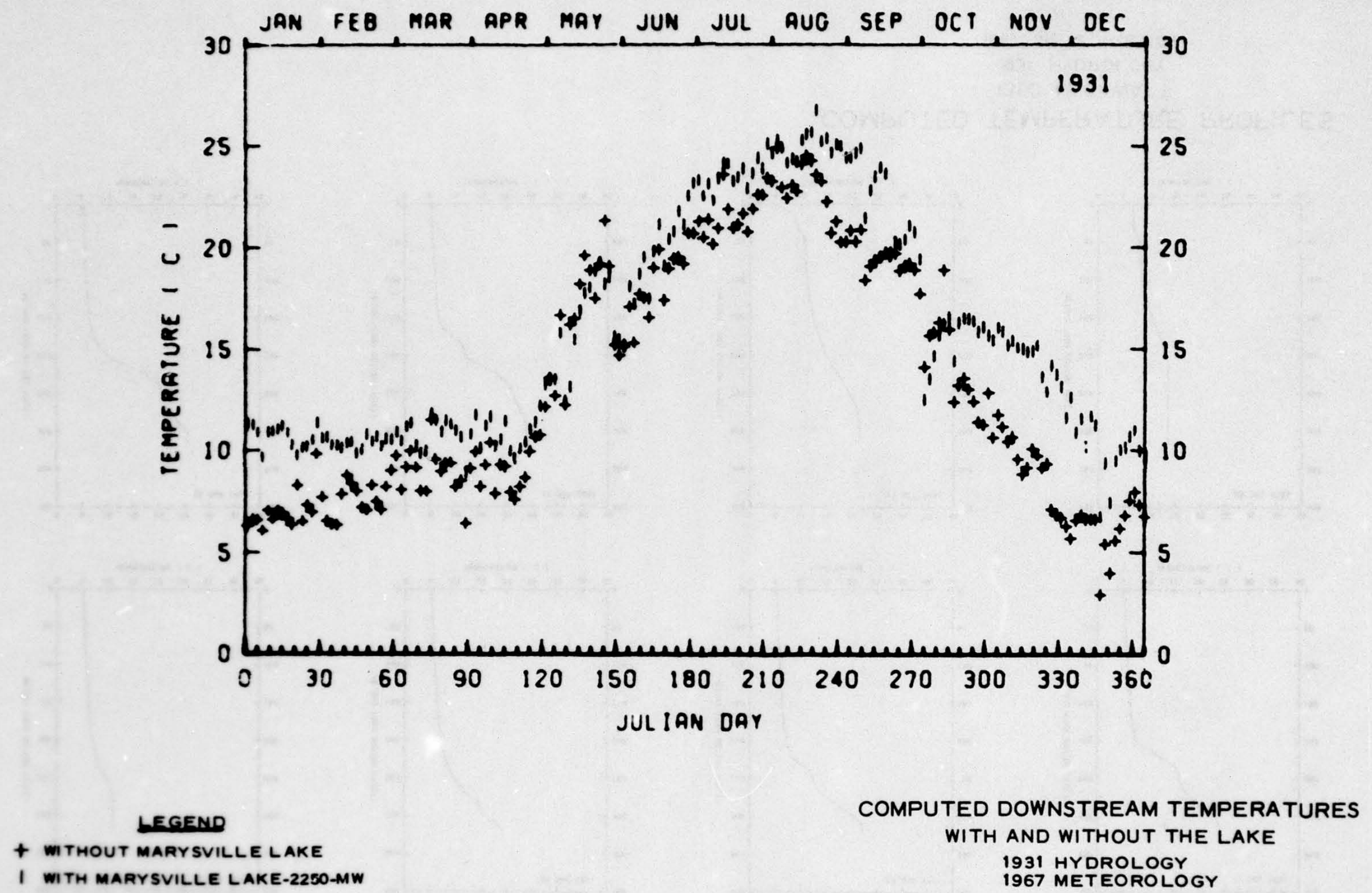
NOTE: THE OBJECTIVE BAND IS APPLICABLE ONLY FOR THE COMPUTED DOWNSTREAM TEMPERATURES. THE BAND ON THE RELEASE AND AFTERBAY TEMPERATURE PLOTS IS FOR REFERENCE ONLY.

2250-MW

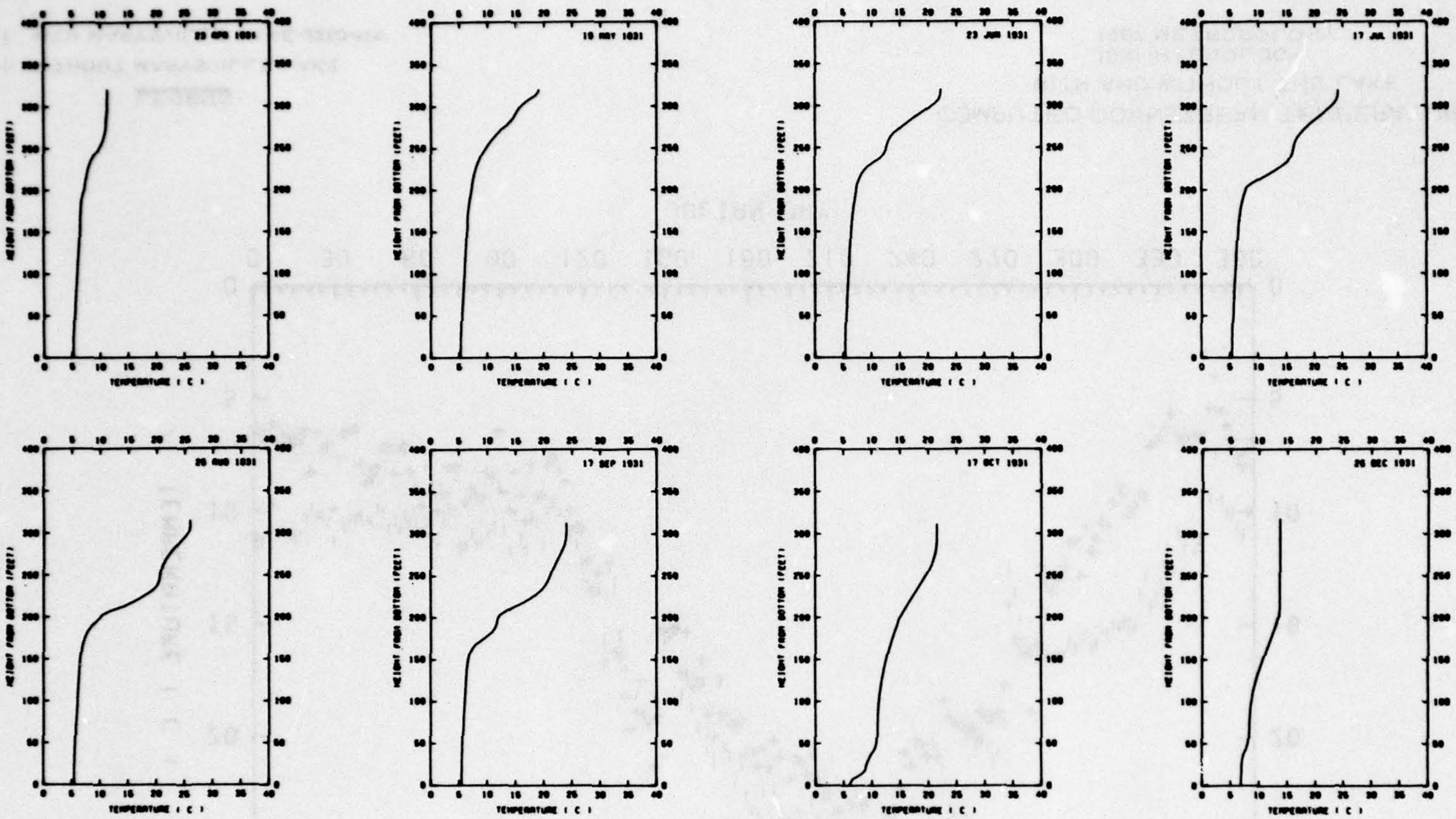
COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM

1931 HYDROLOGY (DRY)

1962 METEOROLOGY (AVERAGE)

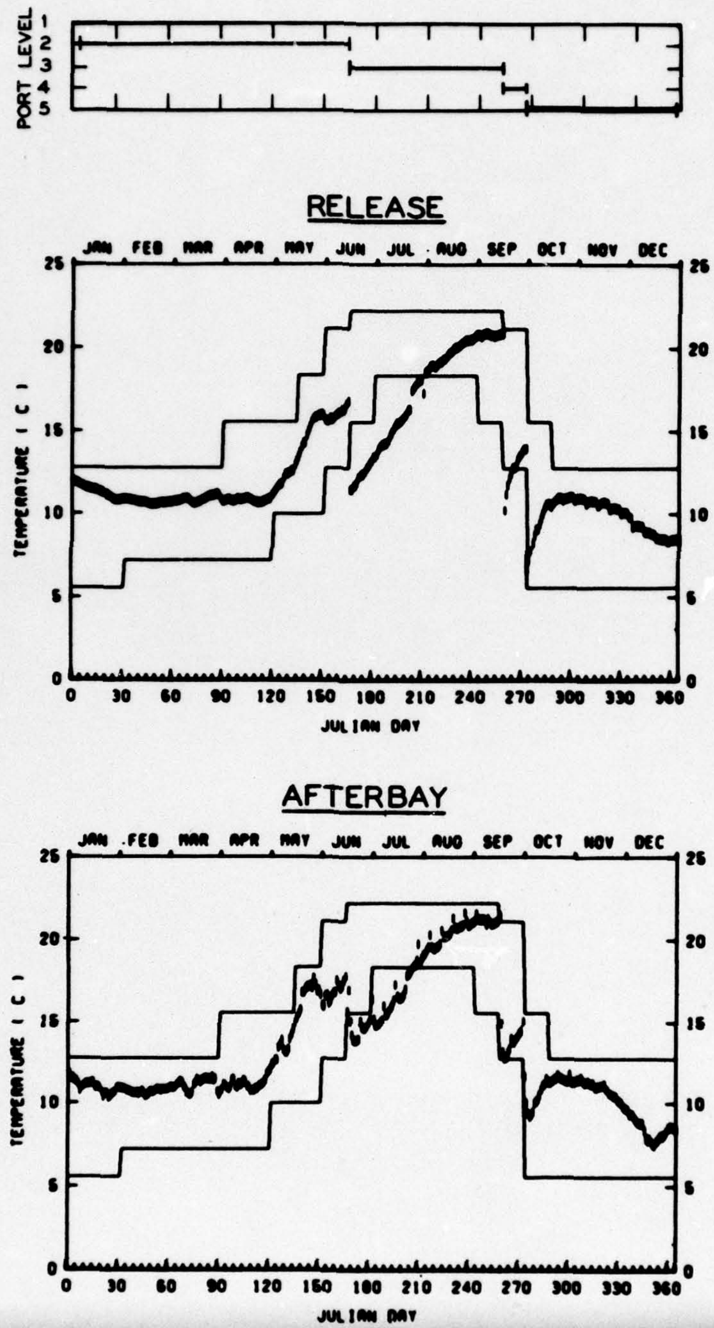


COMPUTED DOWNSTREAM TEMPERATURES
WITH AND WITHOUT THE LAKE
1931 HYDROLOGY
1967 METEOROLOGY



COMPUTED TEMPERATURE PROFILES
1350 MEGAWATT
1931 HYDROLOGY
1967 METEOROLOGY

PLATE 11


PORT LEVEL
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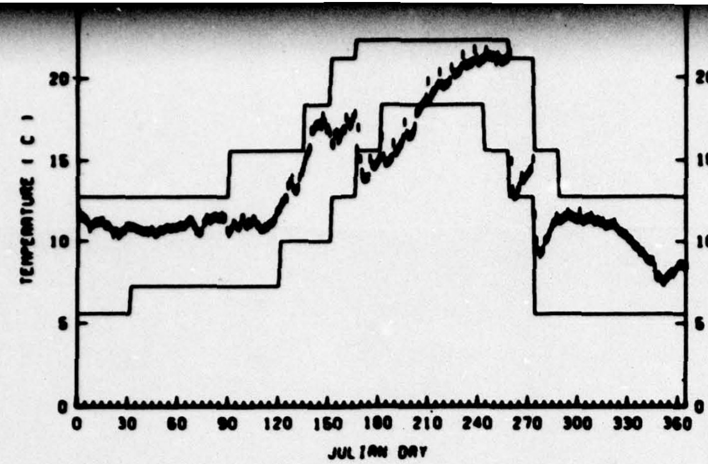
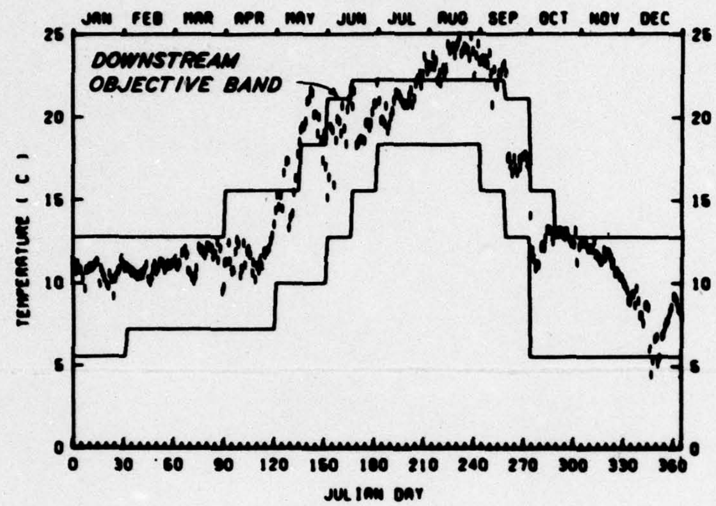
RELEASE
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
0
5
10
15
20
25
0 30 60 90 120 150 180 210 240 270 300 330 360
JULIAN DAY
AFTERBAY
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
TEMPERATURE (C)
0
5
10
15
20
25
0 30 60 90 120 150 180 210 240 270 300 330 360
JULIAN DAY



DOWNSTREAM



NOTE: THE OBJECTIVE BAND IS APPLICABLE ONLY FOR THE COMPUTED DOWNSTREAM TEMPERATURES. THE BAND ON THE RELEASE AND AFTERBAY TEMPERATURE PLOTS IS FOR REFERENCE ONLY.

COMPUTED TEMPERATURES AT THE RELEASE, AFTERBAY, AND DOWNSTREAM
1350 MEGAWATT
1931 HYDROLOGY
1967 METEOROLOGY

In accordance with letter from DAEN-RDC, DAEN-ASI dated 22 July 1977, Subject: Facsimile Catalog Cards for Laboratory Technical Publications, a facsimile catalog card in Library of Congress MARC format is reproduced below.

Dortch, Mark S

Marysville Lake hydrothermal study; Report 2: 2250-MW Project; hydraulic and mathematical model investigation / by Mark S. Dortch. Vicksburg, Miss. : U. S. Waterways Experiment Station ; Springfield, Va. : available from National Technical Information Service, 1978.

20, [19] p., 12 leaves of plates : ill. ; 27 cm. (Technical report - U. S. Army Engineer Waterways Experiment Station ; H-77-5, Report 2)

Prepared for U. S. Army Engineer District, Sacramento, Sacramento, California.

1. Hydraulic models. 2. Hydroelectric power. 3. Marysville Lake. 4. Mathematical models. 5. Pumped storage. 6. Water temperature. I. United States. Army. Corps of Engineers. Sacramento District. II. Series: United States. Waterways Experiment Station, Vicksburg, Miss. Technical report ; H-77-5, Report 2.

TA7.W34 no.H-77-5 Report 2